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Status of pumped hydro-storage schemes and its future in India

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ABSTRACT

The growing economy with corresponding increase in power demand causes more challenges in power sector of developing countries. In India, the increase in peak power demand necessitates energy storage schemes over and above the storage—hydro-, oil- and gas-based peak power plants to ensure power system stability. In utility energy storage schemes, the Pumped storage schemes attract more attention even in the developed countries due to its unique operational flexibility over other energy storage systems. In India, the availability of suitable topographies, hydro-thermal ratio imbalance in various regions, and optimal storage capacity for flexible power system operation gives a thought for the planers and executors to implement these schemes to meet peak demands. This paper presents a critical review of the necessity of pumped storage schemes in India. This review reveals that the major constraint for pumped storage operation in India is the deficit of off-peak power available in all the regional grids except north-east region for pumping at present. But the current adversity is likely to be gradually solved by the commissioning of newly proposed power projects. Fixing of a separate operational tariff for pumped storage schemes throughout the country is another requirement for which the government has set up a one man committee to analyze the feasibility for this peak tariff. Non-availability of lower tail pools and irrigation needs also causes poor pumping operations in some cases. However, most of the states in India are evincing interest in pumped storage schemes and proposals are being submitted to central government for securing stations clearance.

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Contents

1. Introduction: role of bulk energy storage in a power system

Bridging supply–demand gap is a challenging task in a power system. Conventional generating plants such as nuclear and coal based plants cannot adjust their output to address the continuously varying load demand. Further, the stochastic nature of non-conventional energy resources such as wind and solar makes the power schedule more complex. To manage such unexpected load variations, power system generally needs about 8–10% of the reserve in addition to the installed capacity online [1]. Bulk energy storage schemes have been used as reserve and peak load plants in a power system since many decades.

So far, only two storage technologies considered as suitable technologies for large-scale commercial operations are compressed air energy storage (CAES) and the pumped hydro-energy

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storage (PHES). There are only two successful installations of CAES worldwide, one 110 MW capacity in United States and another 290 MW capacity in Germany [2]. The requirement of topology for the installation of these systems is specific, which limits the commissioning. PHES is cheaper compared to CAES, as water is the storage medium.

PHES is the only proven large scale (> 100 Mega Watts (MW)) energy storage schemes for power system operation. Worldwide, there are more than 300 installations with total capacity of 127 Giga Watts (GW) [1,2]. The increasing trend of installations and commercial operation of these schemes has been noticed in recent years [3]. In addition, with the present capacity, it is expected that another 76 GW will be added by 2014 worldwide [1]. Many countries realized the feasibility of this technology and planning for addition of pumped storage capacity to the power system, especially to facilitate the use of renewable energy sources.

In India, planning for integration of the pumped storage schemes started in the 1970s with a view to operate in co-ordination with especially nuclear plants. The first pumped storage plant of the country was commissioned in years 1980–1985 (Nagarjunasagar Pumped Storage Plant) [4]. At present, 11 pumped storage schemes with an installed capacity of 4804 MW are functioning in the country and another 1000 MW capacity plant is under construction. The Central Electricity Authority (CEA—a statutory body of Ministry of Power, Government of India, for the technical coordination and supervision of programmes) has identified 56 potential sites suitable for the development of pumped storage schemes with a probable installed capacity of 94,000 MW [5].

According to construction, pumped storage schemes are similar to the conventional hydro-power plants with the option of pumping. It consists of two reservoirs, one is located at a low level called ‘lower reservoir’ and the other at a higher elevation called ‘upper reservoir’. The power plant is equipped with reversible pump-turbines which can be used for both generation and pumping operation. During off-peak hours of the grid, the water is pumped from the lower to the upper reservoir where it is stored. During peak hours the water is released to the lower reservoir for power generation. Both the reservoirs may be artificial or natural based on topography. If any natural stream flow drives into the upper reservoir, it contributes to additional power generation. Such schemes are called mixed pumped storage schemes and the schemes without natural inflow are called pure pumped storage schemes.

This paper briefly reviews the history of the development of pumped storage schemes in India, the present conditions and the future prospects.

2. Indian energy scenario and the need for pumped storage installation

As per 2011 statistics, India is one of the largest energy producers in the world holding 11th rank and approximately its consumption is 2.4% of the total energy consumption of the world. Also India stands as the sixth largest installed capacity of electricity generation and sixth largest energy consumer of the world [6]. At the time of independence (15 August 1947), only 1362 MW [7] of electricity was produced in India from thermal and hydro-power plants. India paid considerable attention to the generation of power since independence, as a result of which the installed capacity of power has grown remarkably. The installed capacity of the country as on 30 April 2012 is 201,637 MW comprising of hydro (38,990 MW), thermal (133,363 MW), nuclear (4780 MW) and renewable energy sources (RES) (24,914 MW) [8]. Fig. 1 shows the breakup of installed capacity with RES.

It is a great challenge to meet out the supply–demand gap in India due to growing economy and scarcity of power. The power system in India is short of required peaking capacity by about 10% and energy shortage by 15% in most of the states [9]. The growth rate of demand for power in India is higher than that of gross domestic product (GDP) [10]. Various planning reasons, such as over ambitious targets, delay in placement of order for main plant, delay in environment clearances, rehabilitation problems leading to litigations, geological surprises in case of hydro-projects, non-availability of gas, etc., have attributed to shortage of power availability in every 5-year plans [11].

Besides the above reasons, less output from thermal stations and reduction of inflow to the reservoirs due to monsoon failures have also caused shortage of peak power and energy availability [12].

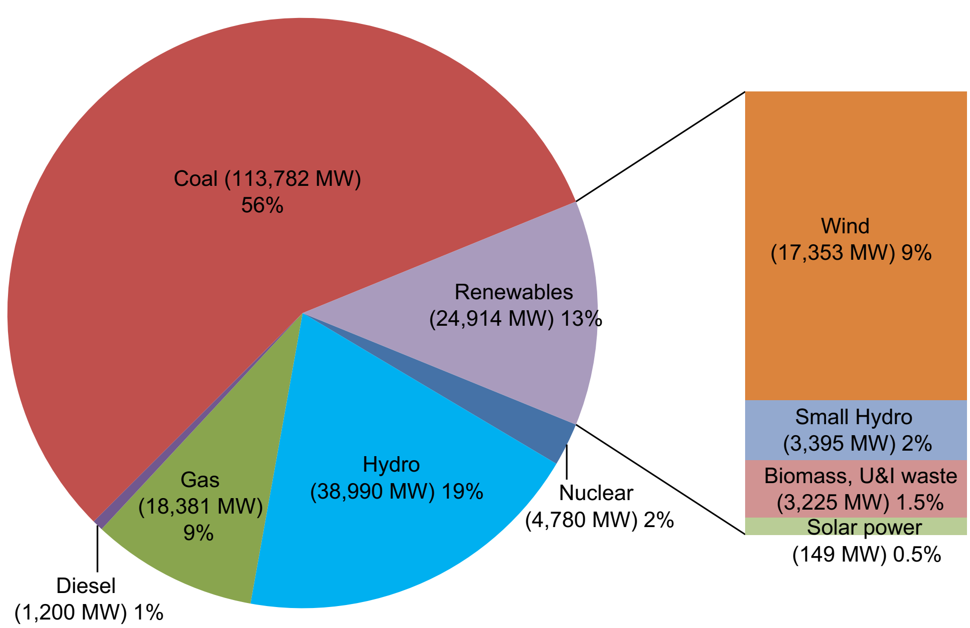

Fig. 1. Installed capacity of the country as on 30 April 2012 [8].

Various schemes including ultra-mega power projects of thermal, nuclear and number of hydro-projects along with RES such as solar, wind and biomass based power projects have been planned and are under execution by the experts during every 5-year plan periods [9]. The concept of the power system to meet the ever growing demand for electricity is base load demand through thermal and nuclear and to meet the peak demand using gas stations, hydro and by pumped storage schemes (PSS). Table 1 indicates the region wise hydro thermal capacity development of the country.

Right from first 5-year plan, the ratio of hydro thermal mix for a stable power system operation in India was taken as 40:60 by the planners [4,13,14]. Accordingly proposals/plans were sanctioned. Table 1 shows the hydro-thermal mix of the country and indicates that it is not optimal in western and eastern regions. These regions have large thermal power plants. Operation of thermal and nuclear stations at high plant load factor will be difficult without support from hydro-stations to take care of the peak load demands. Various studies have thus concluded that the preferable capacity of the pumped storage installation for thermal dominant power system is 4–5% of the total installed capacity [15]. The region wise percentage of PSS capacity over total installed capacity is shown in Table 2.

The above scenario clearly indicates that the stable operation of thermal and nuclear power plants is complicated due to less hydro-thermal ratio. The predominant thermal base of the western and eastern regions implies energy surplus during off peak hours which leads to plan special storage/peak plants for the stable grid operation. The development of Purulia PSS in eastern region and Ghatghar PSS in western region is ensuring optimum utilization of thermal/nuclear power available in these regions. The rise in peak load of the system in many regions except north-eastern region and increasing contribution of thermal and nuclear power often supports the energy storage installations of the country. The multipurpose (i.e. mixed type) pumped storage schemes are identified with supportive topographical settings as suitable energy storage schemes [4,15,16].

3. Historical PSS development in India

In democratic India, all economical implementations have been executed through the 5-year plans. The history of pumped storage schemes in India has been initiated by an action plan of fifth 5-year plan. The 700 MW Nagarjunasagar (1980–1985) pumped storage plant of Andhra Pradesh holds the credit of first installed pumped storage plant of the country. The 12 MW Paithan (1984) pumped storage scheme of Maharashtra is the second installed pumped storage scheme. Both these pumped storage plants were executed by the sixth 5-year plan. The 400 MW Kadamparai (1987–1989) pumped storage plant of Tamil Nadu state was commissioned during seventh 5-year plan. Kadana first stage (1×60 MW) (1990) in Gujarat and Panchet hill second unit (40 MW) under Damodar Valley Corporation (DVC) in Bihar were commissioned in 1990–1991. During the eighth 5-year plan Ujjain (1×12 MW) (1990) and Bhira (1995) (1×150 MW) pumped storage schemes of Maharashtra state were commissioned. One unit of Kadana second stage (1×60 MW) was commissioned in March 1996 and another unit (1×60 MW) commissioned during 1998 in Gujarat. Srisailam Left Bank Power House (LBPH) pumped storage scheme (6×150 MW) in Andhra Pradesh was commissioned in years 2001–2003. Sardar Sarovar Right Bank Power House (RBPH) (6×200 MW) mixed pumped storage was commissioned in 2006 in Gujarat. Purulia, a pure pumped storage plant (4×225 MW) in West Bengal was commissioned in 2007–2008. The Ghatghar PSS (2×125 MW) in Maharashtra, a pure pumped storage, was commissioned during 2008. The Tehri Hydro Development Corporation a public sector enterprise of India constructs country's largest Tehri PSS of 1000 MW (4×250 MW). The highest capacity of mixed type pumped storage plant is under construction in Uttarakhand state and expected to be commissioned by 2016. Table 3 shows the historical development of PSS in the country based on 5-year plans [4,17].

4. Present operational status and constrains in operation of pumped storage schemes in India

At present, 11 pumped storage schemes are located in various states in India. Out of which, nine pumped storage stations are mixed type and 2 are pure pumped storage type. The following eight stations are operated in both the modes i.e. pumping and generation as per the grid requirement: Paithan, Ujjain, Kadamparai, Srisailam, Purulia, Kadana, Bhira and Ghatghar. These pumped storage stations are operating in pumping mode for fewer hours than that contemplated in the project report due to the unavailability of surplus energy in the power system for more hours. It is the prime reason for less overall output from these

Table 1
Region wise hydro-power station installed capacity as on 30 April 2012 and PSS percentage to the total hydro-capacity [8].

Region	Hydro capacity (MW)	Thermal capacity (MW)	PSS capacity (MW)	% of PSS to hydro	% of hydro/thermal nuclear mix ratio
Northern	15,122.75	35,071.75	1000 (under construction)	6.61	43.12
Western	7447.50	49,536.79	1864	25.03	15.03
Southern	11,338.03	29,832.60	2000	17.64	38.01
Eastern	3882.12	22,605.08	940	24.21	17.17
North-eastern	1200.00	1026.94	0	0	116.85

Table 2
Region wise percentage of PSS capacity over total installed capacity.

Region	Total installed capacity (MW)	Installed capacity of PSS (MW)	Number of schemes	% of PSS to total capacity
Northern	54,585.90	1000 (under construction)	1	1.83
Western	64,894.24	1864	6	2.87
Southern	52,739.93	2000	3	3.79
Eastern	26,885.91	940	2	3.50
North-eastern	2454.94	0	0	0

Table 3
Pumped storage growth based on 5-year plans in India.

Plan	Installed capacity of PSS (MW)	Cumulative capacity of PSS at the end of plan (MW)
Up to fifth plan (31-3-1980)	Nil	Nil
Sixth plan (1980–1985)	612 (Nagarjunasagar, Paithan)	612
Seventh plan (1985–1990)	500 (Kadamparai, Nagarjunasagar)	1112
Two annual plans (1990–1992)	160 (Kadana Units: 1 and 2, Panchet hill)	1272
Eighth plan (1992–1997)	222 (Kadana Unit: 3, Bhira, Ujjain)	1494
Ninth plan (1998–2002)	960 (Srisailam, Kadana Unit: 4)	2454
Tenth plan (2002–2007)	2100 (Sardar Sarovar, Purulia)	4554
Eleventh plan (2007–2012)	250 (Ghatghar)	4804
Twelfth plan (from 2012)	1000 (Tehri)	5804

Table 4
Hydro-generation performance data (2010–2011), Hydro Planning & Investigation Division, CEA, August 2011 (units are in million units (MU)).

Station	Designed energy	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003
Purulia	1700	–	–	–	–	–	–	–
Kadamparai	797	131	150	187	143	187	163	203
Bhira	775	–	–	438	597	–	540	565
Ghatghar	410	–	–	–	–	–	–	–
Kadana	518	317	421	405	188	0	41	8
Srisailam	1400	–	–	–	–	–	381	558
Station	**2003–2004**	**2004–2005**	**2005–2006**	**2006–2007**	**2007–2008**	**2008–2009**	**2009–2010**	**2010–2011**
Purulia	–	–	–	–	385	670	867	878
Kadamparai	408	256	581	427	456	294	419	572
Bhira	539	580	701	–	–	–	–	–
Ghatghar	–	–	–	–	–	95	149	350
Kadana	101	362	209	352	299	78	114	118
Srisailam	328	1411	2232	2512	2546	1802	1279	1991

stations. In India, in normal days surplus power is available only during off-peak hours i.e. midnight to 5 am with limited capacity or less than the requirement of pumping capacity of the plant. During national holidays and weekends the machines are operated as pump for more hours since there is low energy consumption by the industrial sector. More surplus power is available during widespread rain in a region when energy for agricultural pumping is not required. However, daily assigned pumping and generating hours have been designed as per Detail Project Report (DPR) e.g. 6 h generation, 8 h pumping for a day for a typical PSS has not been achieved so far. Hence most of the PSS stations achieved 40–50% of the projected design energy as mentioned in DPRs of the corresponding pumped storage plants, since the country is always facing energy shortage (Table 4). In this table only large capacity PSS have been considered, and Paithan and Ujjain PSS of 12 MW capacity have not been considered.

Nagarjunasagar, Panchet hill (DVC) and Sardar Sarovar pumped storage schemes are working as conventional hydro-generators due to more inflow and commitment to irrigation needs. The tail race reservoir is under construction in respect of Nagarjunasagar and Panchet hill stations. Although these power stations have been constructed as pumped storage plants, these are being used for generation only mode since more inflow is available to the respective reservoirs. However, due to upstream developments taking place at present, the corresponding reservoirs are receiving less inflow. Hence the tail race dam is under construction to develop the lower reservoir, so that these stations can also operate in pumping mode. In the case of Sardar Sarovar project, priority is given for irrigation for the period of 5 years and pumping operation from the station will be carried out at a later stage after stabilization of the irrigation lands in desert area [4].

After introduction of Availability Based Tariff (ABT) the frequency variation could be limited within the range of 49.0–50.5 Hz. Prior to the same (pre 2003) the variation in frequency was from below 48.0 to 52.0 Hz on a daily basis [18]. The design frequency of the all-reversible pump/turbine of the country for pumping operation is 49.5–50.5 Hz which is the range fixed by the regulators. The overall unsatisfactory performance of the power sector is reflected in the operation performance of the pumped storage schemes too [19]. The main requirement for satisfactory operation of pumped storage schemes is adequate water in the tail race reservoir and frequency above 49.5 Hz with the availability of required power for pumping. Seven pumped storage schemes were commissioned during the period from 1980 to 2000 and due to the absence of tail race reservoir or non-availability of surplus energy in the system, pumping operations were adversely affected. Hence mostly these PSS were operated in conventional hydro-generating mode to meet irrigation/peak demands. However the performance of these stations in conventional mode has been satisfactory. Improvement in performance of pumped storage plants in Kadamparai, Purulia and Ghatghar can be seen from the energy production data for the period from 1996 to 2011 presented in Table 5, which has been possible due to the implementation of ABT.

In developed countries the operation of pumped storage is based on price-based mechanism, since they have sufficient surplus and various operating arbitrages with incentives for the independent generators. In such environment, the schemes are designed to buy cheap off-peak energy from the grid for pumping and sell the energy during peak hours at a competitive price which is higher than the purchase price. Indian power industry has not yet commenced such a commercial operation of pumped storage, since the cost of common off peak power for pumped storage is yet to be fixed [17,20].

5. Future prospects

As mentioned earlier, CEA has identified 56 potential sites suitable for the development of pumped storage schemes. Fig. 2

Table 5
Hydro generation performance data (2010–2011), Hydro Planning & Investigation Division, CEA, August 2011.

Station	Design energy	1996–1997	1997–1998	1998–1999	1999–2000	2000–2001	2001–2002	2002–2003
Purulia	1700	–	–	–	–	–	–	–
Kadamparai	797	131 (16%)	150 (19%)	187 (23%)	143 (18%)	187 (23%)	163 (20%)	203 (25%)
Ghatghar	410	–	–	–	–	–	–	–
Station	**2003–2004**	**2004–2005**	**2005–2006**	**2006–2007**	**2007–2008**	**2008–2009**	**2009–2010**	**2010–2011**
Purulia	–	–	–	–	384 (23%)	669 (39%)	867 (51%)	878 (52%)
Kadamparai	408 (51%)	256 (32%)	581 (73%)	427 (54%)	456 (57%)	294 (37%)	419 (53%)	572 (72%)
Ghatghar	–	–	–	–	–	95 (23%)	149 (36%)	350 (85%)

Units are in MU and ratio of actual energy generation to design energy is in %.

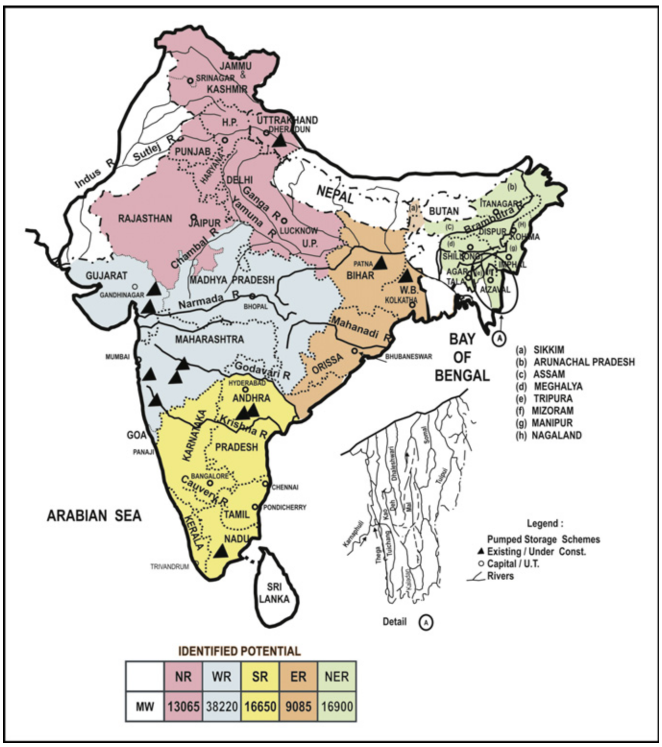

Fig. 2. Existing schemes and region wise identified sites.

shows the potential PSS sites in India and Table 6 indicates the region wise capacity available for PSS development.

Before developing new pumped storage schemes, it is necessary to establish the need for a pumped storage scheme in relation to the total installed capacity and maintaining the base rule of peak load plant to base load plant mix ratio as 40:60. Study reports suggest the optimum installed capacity of pumped storage in a predominant thermal/nuclear would be in the order of 4–5% of the total installed capacity [15].

Increase in RES utilization is another major area of Indian energy sector. The total estimated potential of renewable energy of the country is around 85,000 MW from commercially exploitable sources, i.e., wind, small hydro and biomass/bio-energy excluding solar energy [21]. In 2011–2012 installed capacity of renewable sources has represented nearly 13% of the total installed capacity.

The notable renewable energy in India is the wind energy. The stochastic nature of the wind energy can be managed by combining with energy storage schemes [22]. As on April 2012, 17,353 MW installed capacity of wind energy has been established in the country. Now India is the fifth largest wind power producer in the world. Apart from the above installed capacity,

Table 6
Region wise distributions of identified pumped storage schemes.

Region	No. of identified schemes	Probable installed capacity (MW)
Northern	7	13,065
Western	25	38,220
Southern	8	16,650
Eastern	6	9085
North-eastern	10	16,900

the estimated wind energy potential of the country is 49,130 MW [23]. The efficient utilization of renewable energy can be achieved by coupling the same with pumped storage systems. Similarly, pumped storage schemes can play a vital role in the production of electricity from solar energy (photovoltaic and thermal routes) [24].

Table 7 shows the development of grid connected renewable power in India [25].

Dudhani et al. [10] highlighted the gap between peak load power demand and availability of power at the regional level, and also analyzed how this gap could be bridged by utilizing nation's renewable sources. The analysis and mathematical model reveal surplus energy in all the regions if the renewable energy potential could be tapped to the power grid as utilizable energy and allocated in optimal way since all the grids are interconnected. The major reason for the lack of pumped storage operation is the deficit of surplus power for pumping operation. If the above scenario persists i.e. the planned capacity of renewable energy sources executed in future, the pumping operation could be carried out efficiently and it would increase the overall system efficiency.

6. Schemes cleared by CEA

Only two pumped storage schemes have gone through all the processes laid down by CEA and the remaining proposals are in the planning stage. The two projects are namely, 1000 MW Tehri—II stage in Uttarakhand and the 1000 MW Koyna pumped storage scheme in Maharashtra.

The Tehri project is under construction and expected to be commissioned by 2016. This project is noteworthy because for the first time in the world, a turbine-pump has been designed to cater to the largest head variation in the world. Initially the plant was planned to adopt two speed variable drives for utilizing this high head variations which has been subsequently changed to adopt doubly fed induction generator for variable speed operation [26].

7. Concluding remarks

The pumped storage plants so far established in the country have not been able to function as projected due to non-availability of

Table 7
Development of grid-connected renewable power in India (in MW) [25].

	Achieved		In process	Anticipated	Targets
5-Year plan	Bye the end of the ninth plan (cumulative installed capacity)	10th plan (additions during plan period)	Anticipated in the 11th plan (additions during plan period)	By the end of the 11th plan (cumulative installed capacity)	By the end of the 13th plan (cumulative installed capacity)
Years	Through 2002	2002–2007	2007–2012	Through 2012	Through 2022
Wind	1667	5415	10,500	17,582	40,000
Small hydro	1438	520	1400	3358	6500
Biomass	368	750	2100	3218	7500
Solar	2	1	1000	1003	20,000
Total	3475	6686	15,000	25,161	74,000

surplus energy in the power system to meet the pumping power needs.

In developing economies, where energy demand grows incrementally, it becomes increasingly difficult to bridge the gap between demand and supply. In such a scenario, it becomes extremely difficult to attain a state of surplus energy supply. Hence planning for pure pumped storage schemes needs to be considered with due caution.

With increased harnessing of renewable energy sources like wind and solar, storage of energy plays a vital role for effective utilization of energy produced from such sources. Under this scenario, development of pumped storage schemes needs to be considered.

In future for reservoir based hydropower developments, it may be worthwhile to plan for about 20–25% of capacity for mixed mode operation. Such a situation would insulate the power plant from reduced capacity utilization in the event of lesser inflow into the reservoir due to increased upstream utilization of water and would also help in storage of energy produced from renewable energy sources for use at a later time of need.

Planning for development of pumped storage schemes needs a detailed study of the power system regarding availability of surplus energy, and only after the same is established, implementation should be taken up. Such a calculated strategy can only ensure projected performance bench-mark and financial efficiency.

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